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ABSTRACT

Commissioned for use during the design phase of the "Skills Essential to Learning" (SEL) video project, this concept paper makes a number of suggestions for facilitating effective scientific learning. These include: (1) establishing a positive climate for science learning in which the student can ask and pursue questions, change routes, sources and hypotheses, and has the power to say "I don't know"; (2) allowing students to work cooperatively, to build on the efforts of others, to give credit where it is due, and to organize into groups when necessary; (3) fostering of hypothesizing, predicting, observing, locating information, and isolating the problem, to increase general thinking skills while learning the scientific process; and (4) focusing school science on the everyday experiences of students. It is argued that the most essential insight that students should glean from the science programs is that all life, on both a macro and micro level, is interdependent with other life forms, and dependent on the non-living environment, and that these relationships are worldwide. The real challenge is to create a climate in which children's imagination is sensitized to conceive of what the senses do not convey. Essential ingredients for such an environment are mutual respect and patience. (JB)

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# Concept Paper

# A Climate for Learning Science

Lazer Goldberg
Hofstra University

September 1980

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The Skills Essential to Learning Project is a cooperative effort by state and provincial agencies to strengthen learning skills instruction in American and Canadian Schools. It began in 1973-74 as the result of numerous meetings of educators and educational broadcasters in the United States and Canada. The Project develops television/film series and related print materials for different grade levels to enhance the teaching of thinking skills in the context of major curriculum areas. The initial series, *ThinkAbout*, became available in September 1979 and is being used extensively in the United States and Canada. *ThinkAbout* programs are for grades five and six. They emphasize thinking skills while reviewing language arts, mathematics, and study skills.

The Project's second phase of program development has begun. As required by the education agencies that created *ThinkAbout*, it will result in programs for:

—mathematics education and thinking skills for grade four;

—language arts education and thinking skills for grades seven and eight;

—science education and thinking skills for grades seven and eight;

It is anticipated that additional phases of the Project will develop programs with a thinking skills emphasis for language arts (for primary grades), for mathematics education (for grade three and grades seven and eight), and for social studies education (for grades seven and eight).

The Skills Essential to Learning Project is a project of the Agency for Instructional Television, a nonprofit American-Canadian organization established to strengthen education through television and other technologies. AIT develops joint program projects involving state and provincial agencies, and acquires and distributes a wide variety of television and related print materials for use as major learning resources.

SEL Phase II

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## Preface

With this paper, conceptualization of the seventh and eighth grade science component of the Skills Essential to Learning (SEL) Project is officially underway. Plans call for producing twelve fifteen-minute programs and related print to help eleven-to-thirteen-year-olds learn basic scientific ideas and the fundamental role of reasoning and thinking in any scientific endeavor. Your first reading of Lazer Goldberg's paper will be exciting because it embodies so many suggestions for linking up all of the skills and ideas the SEL Project represents. For example:

* Hypothesizing, predicting, observing, locating information, isolating the problem -- all are general thinking skills indigenous to the scientific process.

* The scientific process is a splendid example of the blending of skills and content -- searching the literature, asking experts, sharing and communicating findings, solving problems of concern to many others as well as oneself. Using skills learned in one content field in another always amazes kids!

* The importance of actually doing science in natural, daily situations common to eleven-to-thirteen-year-olds reflects the SEL Project's goal of having students acquire skills and see the connection between school and their own lives.

But Goldberg's discussion of the climate for learning reflects perhaps the most fundamental of the SEL Project's goals. Here the learner asks and pursues questions relentlessly, changes routes, sources, and hypotheses en route to the solution of a crucial problem such as pollution, has the power to say, "I don't know." Such is the lifeblood of confident, independent learners.

Though Goldberg does not give examples of the uses of television in teaching reasoning and thinking via scientific content, one's

mind overflows with possibilities while reading this paper. Why not, for instance, show kids exploring interesting phenomena in their everyday lives? Why not show a re-creation of the Fleming and Tyndall experiments he mentions? Although the teacher would be hard pressed to do this in the classroom, television can bridge time, re-create history, raise questions, and lead students into the thinking and sorting out process so essential to work in science. In this way television can be an important factor in developing the interest, imagination, and scientific preparedness so crucial for a student's scientific growth as Goldberg describes it.

This paper should be enormously helpful to the Project's instructional designers as they tackle the task of determining from the myriad of possibilities just which science content will be used and how it will carry the reasoning and thinking instruction. Over the next twelve months the designers will sample widely from the suggestions in this paper and combine them with those of other science educators to create a specific detailed plan for each lesson.

Television is a "dandy tool" for skills instruction. And nowhere is its use more important than in strengthening those skills that are at the heart of the curriculum -- the skills essential to learning. Instructional television programs designed around the ideas Goldberg presents can't help but make a significant contribution to the teaching of these skills and to the students whose lives revolve around these "world" concepts.

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# A Climate for Learning Science

The kinds of educational experiences we design ought to be guided by what we believe is good for children while they are growing up and by our understanding of the world in which they will live out their lives as adults. I know something about the former and very little about the latter. The more specific issue is: What ought to be the guiding principles of a program in science that is intended to be truly educative, that will contribute to children's happy and effective growth while preparing them for a world I cannot describe with any degree of accuracy? Among the principles that satisfy these requirements are, I believe, the following: consistency with actual scientific practice, cultivation of scientific literacy, correction of stereotypic notions about scientists and their work, cultivation of a scientific attitude, stimulation of interest in science, and a significant contribution to independent intelligence in assessing the connection between science and the learners' lives. I shall outline a series of ideas which, if skillfully developed, can genuinely educate children in science.

## The search for pattern

We are surrounded by countless varieties of things and events.

We can try to learn these apparently disparate things and events one at a time. That is what people did early in human history. They had names for individual trees, but no word for "tree." They had different number names for counting different things. This ancient and inefficient way of learning is still practiced when students' main preoccupation is the retention of names for those occasions when they are asked to recall them for the record. The information is burdensome and largely useless except for foolish tests. What insight is gained from the names of stars, stones, trees, flowers, or clouds? What pleasure accompanies their recollection? There is another way to learn, a way that is central to scientific effort.

The effort to learn in the spirit of science is characterized by a search for connection. Soap bubbles, the alveoli of the lungs and the villi of the small intestines, the small particulates hanging in the air, the consumption of food by a mole and an elephant, the sizes and shapes of planets, and the architecture of medieval cathedrals, seem unrelated. And yet, if we examine the relationship of surface to volume, we can understand that in various ways, this relationship governs them all. Having grasped this relationship, we regard new experiences in a different way. Notice the housefly standing on the ceiling; how comfortably it appears to rest there. We know that particulates of varying size and shape fall at different rates because of the surface to volume connection; perhaps this connection is also at work in explaining the fly's neat trick.

Having once experienced the satisfying feeling in discerning such connections, the search for new connections becomes exciting. Imagine tracing pizza to the secret processes of an humble blade of grass, measuring the diffusion of gases and deciding that monster ants could not really have existed, or verifying by observing a pendulum that the earth rotates. Finding such connections feels rewarding because it satisfies the human need to know. This kind of knowing makes

our world more understandable, less forbidding and chaotic, more orderly in appearance, and more comfortable to live in.

A cooperative activity

We tend to romanticize science just as we do history and human endeavor in general. Much of the history of science can be described in the same words that Tobias Dantzig used to describe the history of numbers:

> It is not a story of brilliant achievement, heroic deeds or noble sacrifice. It is a story of blind stumbling and chance discovery, of groping in the dark and refusing to admit the light. It is a story replete with obscurantism and prejudice, of sound judgment often eclipsed by loyalty to tradition, and of reason long held subservient to custom. In short, it is a human story.

It is all the more remarkable that science has revealed so much about the universe and about how everything in it is put together. The secret of this immense achievement is cooperation across time and space. Newton had Galileo's and Kepler's work before him, and Einstein had Newton's. Science is the most international of intellectual endeavors. Among the contributors to our knowledge of hormones are Pierre Lyonet (Dutch), Sir Vincent Wigglesworth (English), Stefan Kopéc (Polish), Soichi Fukuda (Japanese), Peter Karlson (German), Carroll Williams (American), Karel Sláma (Czech), and Kailish Saxena (Indian). Similar contributions mark the development of electromagnetism, where the very names of the units, farad, henry, coulumb, volt, ampere, ohm, reveal the international character of the effort. This is also true of astronomy, nuclear energy, geology, and every other major branch of science. Nowadays we can see the international character of science demonstrated in Antarctica. Such cooperative endeavor is inherent in the very nature of science.

That is why young people learning science need to work cooperatively, to build on the efforts of others, to give credit where it is due, and to organize into groups when group efforts are more likely

to be more productive. Searching the literature, or just plain looking it up, implies that others may have suggestions to make in our own work.

Scientific processes, not "The Scientific Method"

Percy W. Bridgman, the American physicist who received the Nobel Prize in 1946, provided the most useful description of method for school science: "The scientist has no other method than doing his damndest." The notion that there is a set of rules, which when properly observed, leads to discovery, is neither true nor helpful. It is no more true of making discoveries in science than of winning games in chess. There are activities, however, that make investigations more promising.

The first of these is to observe carefully. That is not at all the same as seeing casually. Very often people who have witnessed an accident report quite different, sometimes contradictory, descriptions of what happened. They saw, but they did not observe carefully. To observe is to take note of with the mind, and the mode of perception is not restricted to the eyes. Plaster of Paris grows warm as it hardens; covering one ear makes it more difficult to discern the source of a sound; a small bottle of mercury is surprisingly heavy; food is tasteless when the head is stuffy with a cold. Twenty/twenty vision is no guarantee of acute observation. What it requires are interest, a lively imagination, and a prepared mind.

Having found something puzzling, interesting or significant, the observer tries next to find the question or isolate the problem. This is the single most difficult thing to do in scientific investigation. Asking the productive question, like thinking of a line of verse, requires a flight of the imagination. Neither is given by plodding effort or the logical mode of thinking. Asking the telling question is a creative activity. It cannot be compelled by assignment for homework.

What compelled Pasteur to ask: "Are there germs in the air?" What compelled Darwin to ask: "Can the principle of selection, which we have seen so potent in the hands of man, apply under nature?" And what compelled Einstein to wonder what the world would look like if he could travel with the speed of a beam of light? Nothing but their accumulated knowledge, the climate in which they lived and worked, and their creative gifts.

If the question is compelling, then the inquirer ought to use all the available resources to track the mystery down. Combing the library is a good start, but the more commonplace the observation, the more difficult is finding ready answers in a book. What makes a cut apple turn brown? And why does grandmother's suggestion to cover the exposed part of the apple with lemon juice work? Why do our eyes fill with tears when we cut onions, and why does cutting onions under water help? Why is there dust whirling in my room after I have vacuumed the room thoroughly? Why is it so difficult to ride very slowly on a bicycle? Why do pools of water freeze on top first? Why do you have to tilt yourself forward in order to stand up?

Should answers to questions be found in a book, that does not necessarily make the answers persuasive. After all, some books would have us believe that our lives are determined by the configurations of heavenly bodies, that some people can bend metal with their minds alone, that white people are smarter than black people, and other unverified claims. Besides, if what the book says is right, we ought to be able to check it out for ourselves. Then we can believe what makes sense, not just what it says in a book. There are a number of ways to check.

One way is to ask people who may know. The teacher is a first likely authority for students. However, a skillful science teacher, even when she knows the answer, is not likely to ruin a promising investigation by providing it. She is more likely to re-direct the

search by asking more questions. Perhaps there are other knowledgeable adults. Perhaps there is a community resource that can help. One adolescent whose mother was very upset about the large telephone bills, decided to find out how the telephone company kept track of long conversations. She was given a guided tour by the chief engineer who explained the telephone technology. However answers are found, they must remain tentative until they have been checked out independently of the source, and reasonable, comprehensible explanations have been found. Until then all findings are hunches, or more formally, hypotheses.

The checking process, the experiment, must be carefully designed -- the second most demanding task in scientific investigation. Whenever possible, the variables ought to be described so that provision can be made for the necessary controls. Provision should be made for quantitative determinations. If counting and measuring will make the results more reliable, then that is what should be done. Like the question, the experiment cannot be designated for performance at a specified time because it cannot be hurried without damage to its integrity and effectiveness.

The reliability of the experiment is tested by repetition. Should the recognition of independent variables have been inadequate, the teacher may suggest slight variations in subsequent trials. If the youngster made no provision for the shape of the can in the conventional collapsing can experiment, the teacher may suggest that a cylindrical can be used in the second trial.

Sometimes an experiment gives an unexpected result. In the example of the air pressure experiment with a rectangular gallon can, it happens on occasion that the can does not collapse. "Failed" tried and true experiments are wonderful opportunities for genuine science learning. Although it is most often not perceived as a blessing, fortune is really smiling on the science lesson. Now resourcefulness is

really tested. Out goes "But it's supposed to collapse." There is no "supposed to" about natural phenomena. The can does what it does under given conditions. "Can we find out why the can didn't collapse?" the teacher asks.

What made the result expected or surprising was that it was predicted. The entire experimental effort is founded on prediction. If we do the following, we can expect such and such to happen. In addition to experimental prediction, students need experience predicting by extrapolation. The child who wants to calibrate a home-made anemometer cannot possibly take readings at all wind speeds. The extension by extrapolation beyond the graph obtained from the several readings is also a kind of prediction.

Having completed the experiments, the youngster now needs to report the findings. This sharing of results is not a matter of social propriety. It is a necessary step in the scientific process. Until it has been done, no science has been performed. The professional scientist describes the work in a reputable journal, presents the work in person at a conference of peers, or both. This is our model for school science. Students may choose to write about their work. These reports ought to be available to anyone in the class or even outside the class. They may choose to present their work in front of their peers. Often the personal presentation is more interesting, especially if demonstrations are included. The teacher can organize an informal conference, including pre-conference refreshments, at which several presentations are made. The presentations, whether written or oral, must be sufficiently clear so that anyone repeating the procedure is bound to get similar results. Others must be able to replicate the work. It is clear, therefore, that there cannot be secrets in science.

These, <u>in general</u>, are the vital processes for work in science. They do not constitute a paradigm. The child who carefully tests the ice with her toe, or who lets a ball fall to test its bouncing quality,

may be inaugurating investigation with these informal experiments. Occasionally, emulating Einstein, a student may prefer to work with pencil and paper alone. Such was the case of a young woman investigating the elegance of beehive structure. The reasoning about the shape of the cells was largely deductive. Her presentation at the blackboard was roundly applauded by her peers. The child who kept track of the sun's shadows for an entire year could hardly control the independent variables. The child who asked why, given the countless stars, the sky was not bright all the time, could find nothing helpful in the library. Nor were available adults helpful. So it goes sometimes. The processes are available techniques. There is nothing rigid about their use. All that is expected is that work be honest, that it tax the investigator's resourcefulness, and that the results be reported.

Error and failure

If the work in school is to reflect the real world of science, error and failure in independent work must be normal to children's experience. It is most unlikely that children who ask real, not bookish, questions about natural phenomena will arrive at neat solutions. They will run into dead ends, confront inconsistencies, realize mistaken assumptions, miscalculate, and suffer many of the other difficulties and pitfalls that plague scientists searching for more proximate truth.

Learning to turn oneself around and try another tack, to check the work, to accept constructive criticism, to ponder the difficulties, to persist, to be daring in ideas and walk alone if necessary, to accept defeat gracefully -- are educative experiences. The answers that students find are already in the literature. Aside from having mastered the skill to extract them, there is little significant educative value in coming up with the right answers apart from the experience of the genuine scientific search. Investigations that reveal imagination, resourcefulness, persistence, clarity of presentation, and above all,

honesty, ought to be applauded by teacher and peers irrespective of the validity of the findings. Should the results be wrong or doubtful, what can be reasonably expected is that the investigator outline proposals for continued work and that he or she listen attentively to suggestions from peers. To have really tried and failed is entirely respectable.

Not knowing is almost always a sign of defeat in school. To confess ignorance is usually to confess inadequacy, failure to have done assigned homework, to have not paid attention, or to be slow and stupid. And yet, in the absence of sufficient information, it is intelligent not to know. Young people are impressed that this is so by playing a variety of games. One of these is the shadow game. Students observe a screen on which the teacher casts shadows in front of a projector. They may guess what the object casting the shadow is. If they are mistaken, they may not guess again until the next object is shown. However, they need not guess wildly. They may say, "I don't know. I need more information. Will you please...?" They instruct the teacher to move the object in a specified way. When they have sufficient clues, they may name the object. It soon becomes obvious that it is foolish to conclude that a straight line shadow is necessarily cast by a string. It may actually be a phonograph record turned on edge. Twenty Questions is another game that conveys this insight. In all such games the clever strategy is to draw conclusions only after sufficient information has been obtained.

## The surprising in the commonplace

The proper focus of school science is on the everyday experiences of youngsters. The distillation from the history of science that appears in textbooks and trade books, films, filmstrips, museum collections, and television programs, when skillfully employed, serves as a resource to illuminate those experiences. A number of considerations

recommend this point of view.

Our culture is powered and driven by science and sophisticated technology. Acculturating children to this society -- a prime function of school -- requires among other things, that they be made conversant with its dominant ethos. Irrespective of what kinds of work children will eventually do, where they will live, or how they will live, their lives will be conditioned by science and technology. They can learn to respond to these forces intelligently, actively, even self-consciously, or they can become aliens in their own land by default. It is not comfortable or satisfying to be an alien. It leads to a sense of helplessness and anomie. To foster a sense of power, of inclusion, requires in the first place that the young understand their own immediate environments, their own commonplace experiences, and the underlying forces at work that make these comprehensible.

To make such experiences the concern of school science is to make science relevant to the lives of young people. The demand for "relevance" in the 1960's often went to ridiculous ends, but there was a sound kernel of validity in it. Why burden students with pretentious gravitational theory when they have not yet considered why the water comes up to their faucet in apparent defiance of gravity? Why leap to the unseen capillarity inside trees before examining the peculiar behavior of a sugar cube touching tea, or a towel dripping water over the sink? Perhaps a comparison of the magnificent sensitivity of the hand with the relative insensitivity of the back will suggest evolutionary processes. Let us find out where the worn-out parts of automobile tires and brake linings go. Is air pollution a genuine concern? We can learn some aerodynamics by studying the flying kite, but we are stumped by the flying frisbee. When you ride in the car, the farther away things are, the more slowly they appear to move. We may more readily understand why, for practical purposes, we can consider the stars as fixed. "I eat junk food all the time, and I feel fine," says

a youngster. Such a claim can be investigated. "How come in junior high school most of the girls look older than most of the boys?" Such a question can be explored. If we listen to the real questions that children ask or would ask if they felt really free to do so, we can teach the science of any curriculum. Any science is no longer remote. It is everywhere our interest leads us.

This is not to suggest that the science program ought to depend, in its structure, upon the questions raised by students. That is too precarious an undertaking. How is the teacher to be prepared for such a program? How are we to plan the growth and deepening of children's understanding? How are the materials to be collected for uncertain projects? No, the curriculum cannot rest on the incidental experiences children bring to school. But investigation, exercising the processes of science, ought to begin with such experiences.

## The prepared mind

The analogy is frequently drawn between the work of a scientist and that of a police detective. The comparison can be instructive if we take note that a detective often has difficulty searching for the relevant facts (clues) until he knows a motive for the crime. This is especially true in homicides. It is extremely difficult to find a killer who is hired, whose only motive for the crime is the money he will collect from the unknown person who hired him. In these circumstances it appears that the crime is random, unrelated to the victim's life. With no connections between the life of the victim and the life of the killer, barring accidents such as eye-witnesses, the detective does not know which are the significant facts to which he ought to attend.

The scientist, too, needs a framework to serve as guide in the search for relevant information. It is a misrepresentation of science to suggest that scientists gather facts until they have enough of them

to make a discovery. John Tyndall, an Irish physicist and popularizer of science, had noticed that some molds are destructive of bacteria some fifty years before Sir Alexander Fleming, a Scottish bacteriologist, made the observation. Why did not Tyndall discover Penicillin notatum? Fleming's discovery in 1928 is often described as an accident. But why did the accident happen to him? Why did it not happen to Tyndall or to the workers in Fleming's laboratory who must have discarded many samples of infected bacteria cultures? "In experimental science," Pasteur said, "chance favors only the prepared mind." Tyndall's mind and the minds of the laboratory workers were not prepared to note the significance of what they observed. Like the killing for hire, the killing of bacteria appeared to be a random event.

In the absence of appropriate intellectual preparation it is possible to misperceive what, indeed, the facts are. When astrologers predict a person's future from the person's time of birth, they ignore the fact that light takes time to travel. For example, if a person was born when Taurus was the ascendant, Taurus was not actually in the observed position. The observer of the star Aldebaran, the brightest identifying star in Taurus, was seeing that star as it was sixty-eight years before. At the velocity of light, 3 x 105 km/sec, that is how long it takes for the light to reach us. But such facts do not dismay the astrologer or the millions of Americans who believe in astrology. A Gallup poll in 1975 reported that 32 million Americans believe in astrology. TWA Ambassador, in an article entitled "Is Business Taurish on Astrology?" (Vol. 12, No. 5), reported that "Astrology is no laughing matter to many businessmen who consult the stars for advice on hiring and firing, the timing of new product releases and business deals." The minds of astrologers and their followers are not prepared to discern what the relevant facts are.

Charles Darwin's theory of evolution by natural selection is frequently cited as evidence for the notion that scientific discovery

is largely a matter of collecting a sufficient number of facts. Did not his voyage on the Beagle serve to fill his notebooks with facts? Did not his observations on the Galapagos Islands, especially of the finches, trigger his conclusions? Darwin's notebooks reveal that he had been pondering the mystery of life's diverse forms for a long time, that he had been asking the crucial questions, that he had had hunches about the process, but lacked evidence.

If facts were all, Carolus Linnaeus, a Swedish botanist and founder of the science of taxonomy, should have discovered the principle of evolution more than a hundred years before Darwin. The tenth edition of Linnaeus' classic work, Systema Naturae, consisted of 2,500 pages of facts about the earth's organisms, surely a sufficient number, if facts were all.

But facts are not all. Nor is it likely that an intelligent decision can be made about which facts are significant to a particular investigation until the investigator's mind is reasonably informed -- another reason to search the library, the minds of reliable sources, authorities in the field. The information thus gleaned will help the investigator reflect on the kinds of information to seek and the meaning of the information already found.

Aesthetic satisfaction in scientific work

Scientific work is more than a cognitive activity because it is done by people, and people are not just cognitive creatures. They also have feelings. While it is true that science primarily satisfies the need to know, it also satisfies the need to feel order, simplicity, elegance, beauty. James D. Watson, co-discoverer of the DNA structure, describes the a-helix demonstrated by Linus Pauling as "uniquely beautiful." We generally reserve experiences of the beautiful to the arts, but it is a mistake to completely segregate the two visions, the artistic and the scientific. Neither the objects of study nor the students

are well served by such segregation. Experiences in science ought not to be completely reduced to right and wrong answers.

Sometimes right answers are pleasing in a way their rightness does not explain. Such was the case when a little first grader announced that he had made a shape out of clay which, when held to the light, always gave the same shadow no matter how the shape was turned. The observers' faces registered awe, admiration, delight, rather than approval. Sometimes the vision and daring of a proposed solution is to be applauded even when it turns out to be wrong. The suggestion by a young girl that she could calculate the area of an irregular, simple closed curve by tracing its outline with a string and then reconstructing the shape into a rectangle, was greeted by cheers and applause from her peers, and by commendation and encouragement from the teacher. Subsequent investigation showed that the perimeter does not give the area. The student's originality of mind was held in high regard nevertheless. Sometimes judgment about right and wrong appears totally irrelevant. When several junior high students generated lovely Lissajous figures with the help of a compound pendulum, the designs were mounted and exhibited for their pleasing shapes.

Values that inhere within scientific activity

The value, above all others, that characterizes scientific activity is, in the words of J. Bronowski, "the habit of truth." That is not because scientists, in their role as citizens, are more moral than the rest of us. It is because truthfulness is a strict requirement for their work. Besides, since all claims to newly discovered knowledge are subject to replication by colleagues, false claims are inevitably exposed. Fraud is rare in science.

It has not always been so. There was a time, before the introduction of modern science, when what was true depended on who proclaimed the truth. The scientific revolution introduced the novel idea

that in matters of validity -- of truthfulness -- neither social, political, or economic status, nor caste, race, sex, bodily form, personality and temperament, or popularity is relevant. What matters is whether findings, when matched against the real world, fit properly. One's findings, when consistently verified by such tests, make one an authority. In science, as in geometry, there is no royal road. Science is fundamentally non-authoritarian.

It follows that if school science is to emulate the real world of science -- except in cases of emergency (fire drills) and immediate threat to health and safety (experiments with household current, toxic chemicals) -- the case is not made simply because the proponent is the teacher. This precept of science is eminently democratic. It means that anyone who wants to learn science may make a contribution.

Since anyone devoted to the search for new insights may have something to contribute, we are obliged to listen respectfully, even when what we hear conflicts with what we believe. Tolerance for well-reasoned opposing views is another condition for successful work in science.

Having listened and been persuaded, we are obliged to hold our ground even in the lonely circumstances when we find ourselves a minority of one. In fact, daring to be a lonely voice is one of the unstated conditions for membership in the scientific community. "If you want to join us," the silent rule says, "you must work very hard to find our work in some way inadequate. We shall resist your efforts to overturn what we have held so dear, but you must persist until the truth is known."

There is no known way to transmit values in a direct way, by instruction. There is no way to prove, in the sense of proving a theorem, that one set of values is superior to another. How does one prove that, in general, telling the truth is superior to lying? What we can do is to serve as a model for these values in the classroom. Except for the special circumstances noted, the teacher ought to be an authority

but certainly not authoritarian. No one's views, not those of the Principal or even of the President, are exempted from examination and informed criticism. Lonely voices ought to be protected from mass assault. Finally, students ought to be given opportunities to examine their values, judge the likely consequences of acting on them, and decide whether they like those consequences. (See my Learning to Choose, Scribner's, 1976.)

Interdependence

The fundamental unstated assumption of education is that the students now in school will find, upon reaching their maturity, a world in which they can fulfill their humanity. In the past this tacit assumption was not subject to serious challenge. That is no longer true. Two dangers threaten these youngsters' future, nuclear war and a deteriorating natural environment. It is the responsibility of school science to equip students with an understanding of the science that lies at the basis of both problems. Too many adults, including political leaders, think of nuclear war as just another war, but with more destructive weapons, and of environmental decay as a minor issue raised by romantics and bird-watcher types. Such thinking can prove catastrophic. It is of the utmost importance that such thinking is rejected by the majority of our citizenry. In this effort the science program can contribute significantly.

The most essential insight that students should glean from the science programs is that all life, on both a macro and micro level, is interdependent with other life forms, and dependent on the non-living environment. These relationships, which John Storer calls "the web of life" are worldwide.

We know very little about these complex interdependent patterns. We know that the top inch of soil is precious and must be alive if it is to feed us; that the tiny phytoplankton in the oceans are

life-givers to us all; that smoke from factories in the Midwest can kill the fish in the Adirondacks with acid rain; that toxic chemical wastes can pollute our drinking water; that we all carry polychlorinated biphenyls in our bodies; that even the Antarctic waters are not immune to our poisonous discharges. We know these things and much more, but there is still more we do not know. In these circumstances it may be best to follow the advice of Claude Bernard, the French physiologist of the 19th century: "In ignorance, refrain."

A climate for learning science

As I have written elsewhere: "The real challenge is to cultivate an air, a climate, in which children's imagination is sensitized to conceive of what the senses do not convey, to have wild, exciting ideas, the kind that call a halt in the ongoing transactions because flights of the imagination appear unrelated, at least for a little while, to all that has gone before. Essential ingredients for such an environment are mutual respect and patience. It is an environment which provides time to tinker and fail, time to chat and to reflect, to stare vacantly, while the elusive threads tangled deep below disengage themselves and find their way to consciousness.

It is a happy place not governed by a scarcity economy of good feelings that are the rewards of pleased adults, but one filled with activity, where feelings are associated with the task and the acceptance of one's fellows. It is a place where joys and sorrows, as well as knowledge, are shared. It is a community."

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The Agency for Instructional Television is a nonprofit American-Canadian organization established in 1973 to strengthen education through television and other technologies. AIT develops joint program projects involving state and provincial agencies, and acquires and distributes a wide variety of television and related printed materials for use as major learning resources. It makes many of the television materials available in audiovisual formats. AIT's predecessor organization, National Instructional Television, was founded in 1962. The AIT main offices and Midwestern office are in Bloomington, Indiana; there also are regional offices in the Washington, D.C. and San Francisco areas.